Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

DEVELOPMENT OF A SNOW SPORTS HELMET INTEGRATING A 3D-PRINTED TRIPLY PERIODIC MINIMAL SURFACE FOAM

Karim KERKOUCHE[1], Yvan PETIT[1], Clément REY[1,2], Giuseppe ROSI[3], Christelle COMBESCURE[4,5], Eric WAGNAC[1]
[1]Department of Mechanical Engineering, École de technologie supérieure, Montréal, Québec H3C 1K3, Canada
[2]Université Paris-Sarclay, Gif-sur-Yvette 91190, France
[3]Université Paris Est Creteil, Université Gustave Eiffel, CNRS, UMR 8208, MSME, F-94010 Créteil, France
[4]Saint-Cyr Coëtquidan Military Academy, CReC Saint-Cyr, 56381 Guer Cedex, France
[5]Université Bretagne Sud, UMR CNRS 6027, IRDL, F-56100 Lorient, France
*eric.wagnac@etsmtl.ca

ABSTRACT

Helmets are a critical component of personal protective equipment for sports and recreational activities that involve a risk of head impacts. Their primary function is to mitigate severe traumatic brain injuries (TBI), especially in snow sport activities. In these disciplines, helmets are generally made with expanded polystyrene (EPS), a material engineered to undergo plastic deformation upon impact. This energy dissipation mechanism protects well against severe TBI but is less effective against mild TBI, including sport-related concussions (SRC). Snow sports are widely practiced by young individuals whose neurodevelopmental processes are still ongoing, rendering them more vulnerable to SRC. Even a seemingly minor fall on compacted snow can result in SRC, underscoring the need for helmet designs that extend protection beyond severe trauma to include lower-impact brain injuries. Given this understanding, there is a compelling rationale for developing snow sports helmets optimized for mitigating SRC.

This study seeks to address this limitation by designing and assessing the performance of a snow sports helmet prototype integrating a 3D-printed triply periodic minimal surface (TPMS) foam. The mechanical behavior of twelve TPMS foam samples with varying unit cell topology and density was characterized under impact loading using a drop tower. The stress-strain (SS) curves of each TPMS configuration were then compared to the SS curve of a conventional EPS sample to identify the most promising TMPS structure based on its energy absorption properties. The EPS liner of a reference snow sports helmet (Decathlon, WEDZE H100) was replaced with a 3D-printed liner featuring the selected TPMS, specifically a gyroid unit cell structure with a 6 mm characteristic dimension and a relative density of 40%, resulting in a helmet prototype. The safety performance of both the reference and prototype helmets was subsequently evaluated using a protocol inspired by the Snow Sports Helmet STAR Protocol (Virginia Tech Helmet Lab). This protocol involves impact testing on a drop tower under six distinct configurations, defined by a single impact speed (6.7 m/s), three impact locations (front, side and rear boss) and two flat-angle anvil (35° and 55°). A STAR value, calculated from the peak linear acceleration and rotational velocity, was determined for each helmet, with a lower score indicating improved safety performance. The prototype helmet (0.65) exhibited a STAR value comparable to the value of the reference helmet (0.66). Accordingly, future work will focus on optimizing the TPMS structure by refining cell size and relative density to enhance protective performance.